Possible Next Generation Reactors – Advanced Material Research Needs

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Introduction

- Research reactors are a critical resource to enable nuclear energy applications including
  - Workforce training
  - Fuels and materials research
    - Optimization of Light Water Reactors (LWR)
    - Development of fuels and materials for GEN-IV reactor concepts
    - Special purpose reactors (research reactors, isotope production, space reactors, …)
  - Technology demonstrations for advanced reactor systems

- **Research reactors are required to conduct high risk, high uncertainty experiments in a controlled, representative environment prior to insertion in a power reactor**

Research Reactor Need Spectrum

Nuclear Physics
- Critical Facilities and training reactors

Materials Behavior
- Open core MTRs

Integrated Fuel Performance
- Loop based MTRs

Off-Normal Fuel Performance
- Transient test reactors

Reactor System Prototype
- Technology demonstration reactors

Any nuclear country

Regional Centers

International Centers

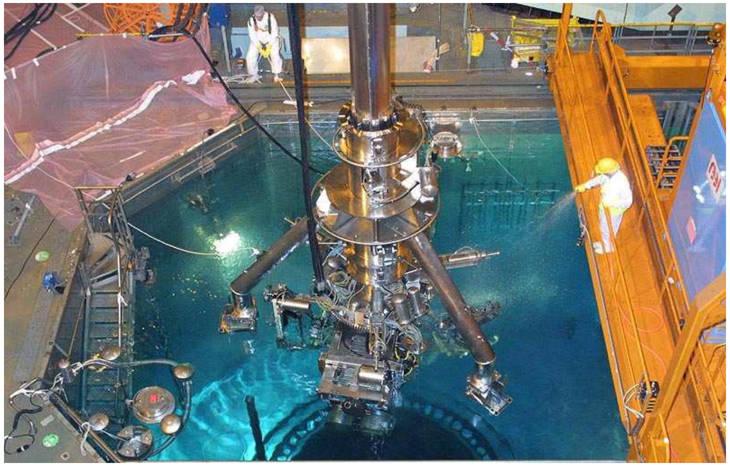
Adv. Technology Developers

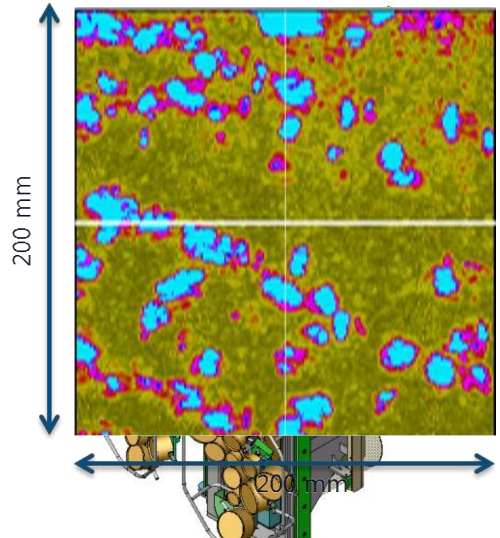
LWR Applications for Materials Test Reactors

- Resolve emerging operations and safety issues
- Enable optimization of existing designs
- Develop new technology

Example of LWR Issue Resolution

- License extension request for Belgian power reactors required 'health assessment'
- Application of modern non-destructive inspection tools identified defects in reactor pressure vessel
- Updated safety analysis required understanding of material properties
- **How can the material behavior after 20 years of additional irradiation be projected?**

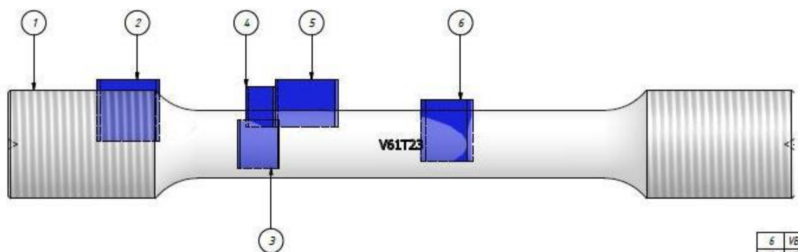




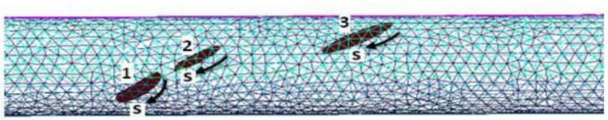
All flaws in first 25 mm of base metal projected in one plane

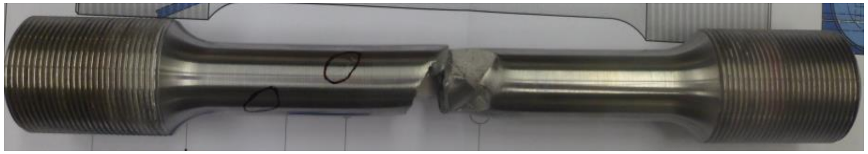
Accelerated Aging of Materials

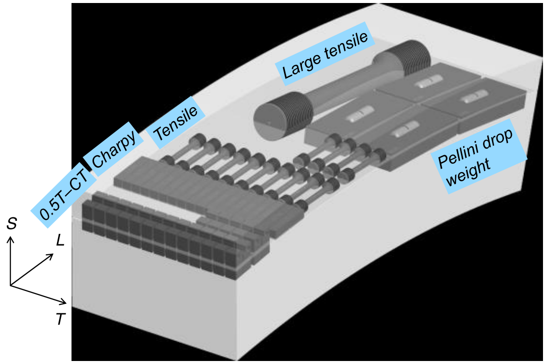
- A representative material with similar defects was identified (from a rejected steam generator)
- Samples were extracted form the material and characterized
- Samples were irradiated in the BR2 reactor in a high neutron flux position to accumulate irradiation damage
- Post irradiation examination was conducted to evaluate the impact of the defects on performance



6	VB39561-v2376	FLAKE
5	VB39561-v2362	FLAKE
4	VB39561-v2358	FLAKE
3	VB39561-v2355	FLAKE
2	VB39561-v2345	FLAKE
1	V61T23	TENSILE (M40X290)







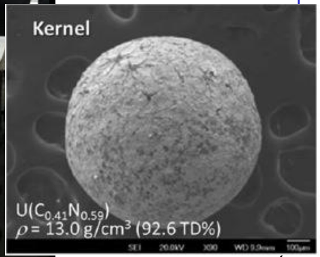
Optimization and Advanced LWR Fuel Designs

- Improved reliability, power uprates, and burnup extension
  - Advanced cladding or pellet development and qualification
  - Demonstration of performance under new operating conditions
  - Improved evaluation of off-normal fuel performance (improved regulatory rules)

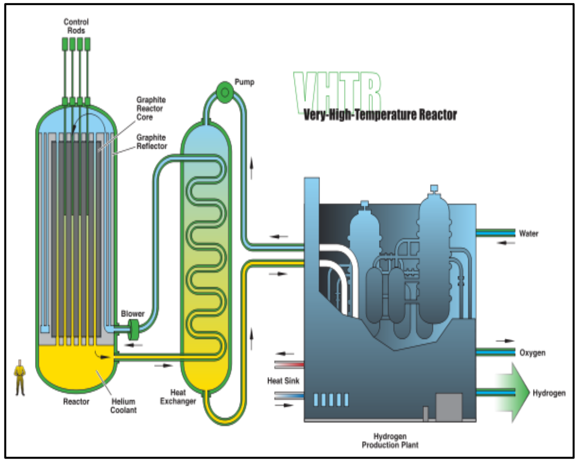
- **Example**: Development of Advanced Fuel Designs
  - Testing of Accident Tolerant Fuel Designs for use in current generation LWR

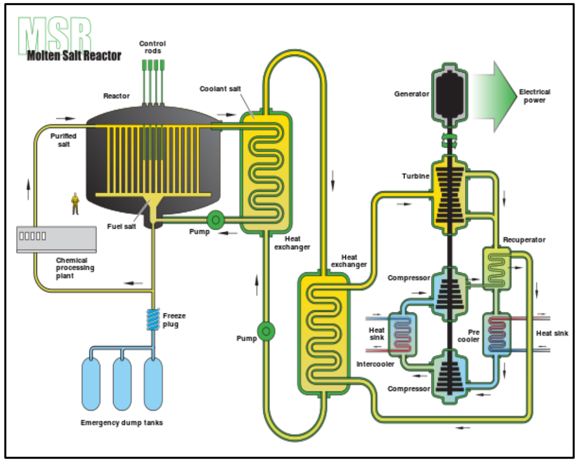
High performance accident tolerant LWR fuels

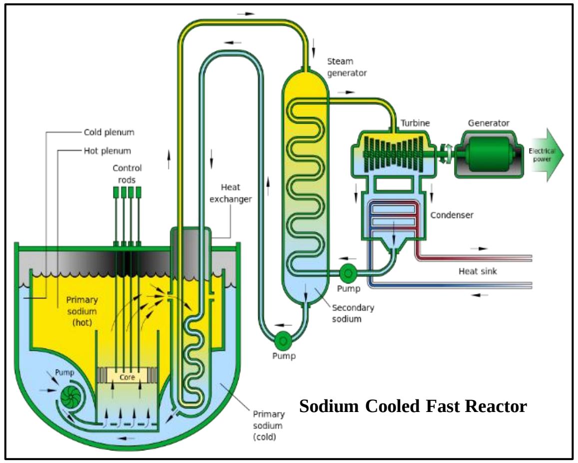
- **Accident tolerant**
- **Ceramic coated zircaloys**
- **Multi-layer ceramic claddings**
- **High density ceramics**
- **High thermal performance**

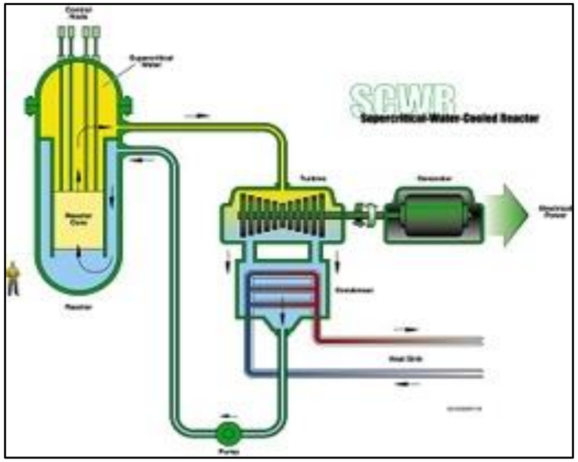


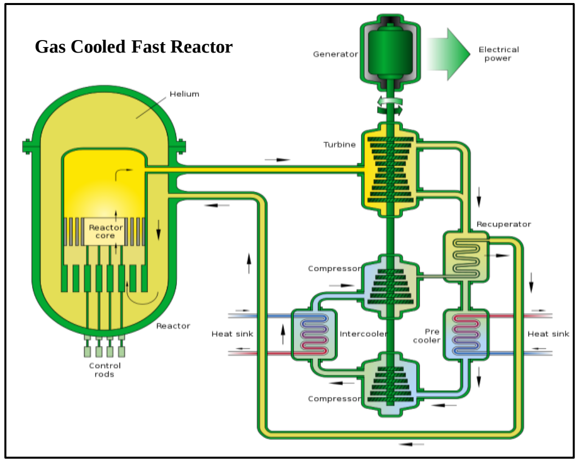
GEN-IV Reactor Systems Require New Fuels

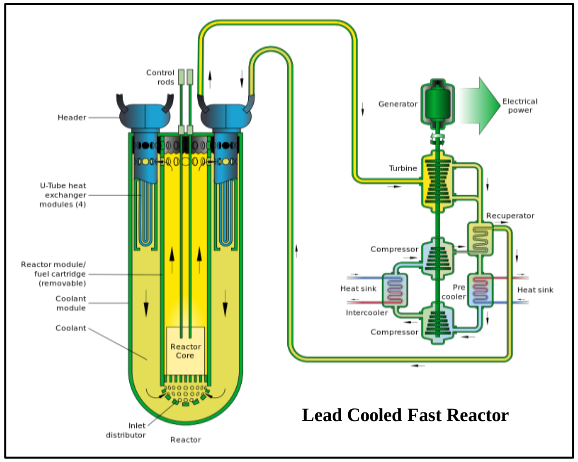












https://www.gen-4.org/gif/jcms/c_40465/generation-iv-systems

GENIV – General Features

System	Spectrum	Coolant	Outlet T (°C)	Likely fuel system
VHTR (very-high-temperature reactor)	**Thermal**	**Helium**	**900-1000**	TRISO Pebble or Prismatic
SFR (sodium cooled fast reactor)	**Fast**	**Sodium**	**500-550**	Metallic/Oxide/Nitride/Carbide
SCWR (super critical water reactor)	**Thermal/fast**	**Water**	**510-625**	Oxide in high temp corrosion resistant steel
GFR (gas-cooled fast reactor)	**Fast**	**Helium**	**850**	Carbide in dispersion or pin SiC
LFR (lead-cooled fast reactor)	**Fast**	**Lead**	**480-570**	Metallic/Oxide/Nitride/Carbide
MSR (molten salt reactor)	**Thermal/Fast**	**Fluoride/ chloride salts**	**700-800**	Liquid fuel or TRISO particle

https://www.gen-4.org/gif/jcms/c_9353/systems

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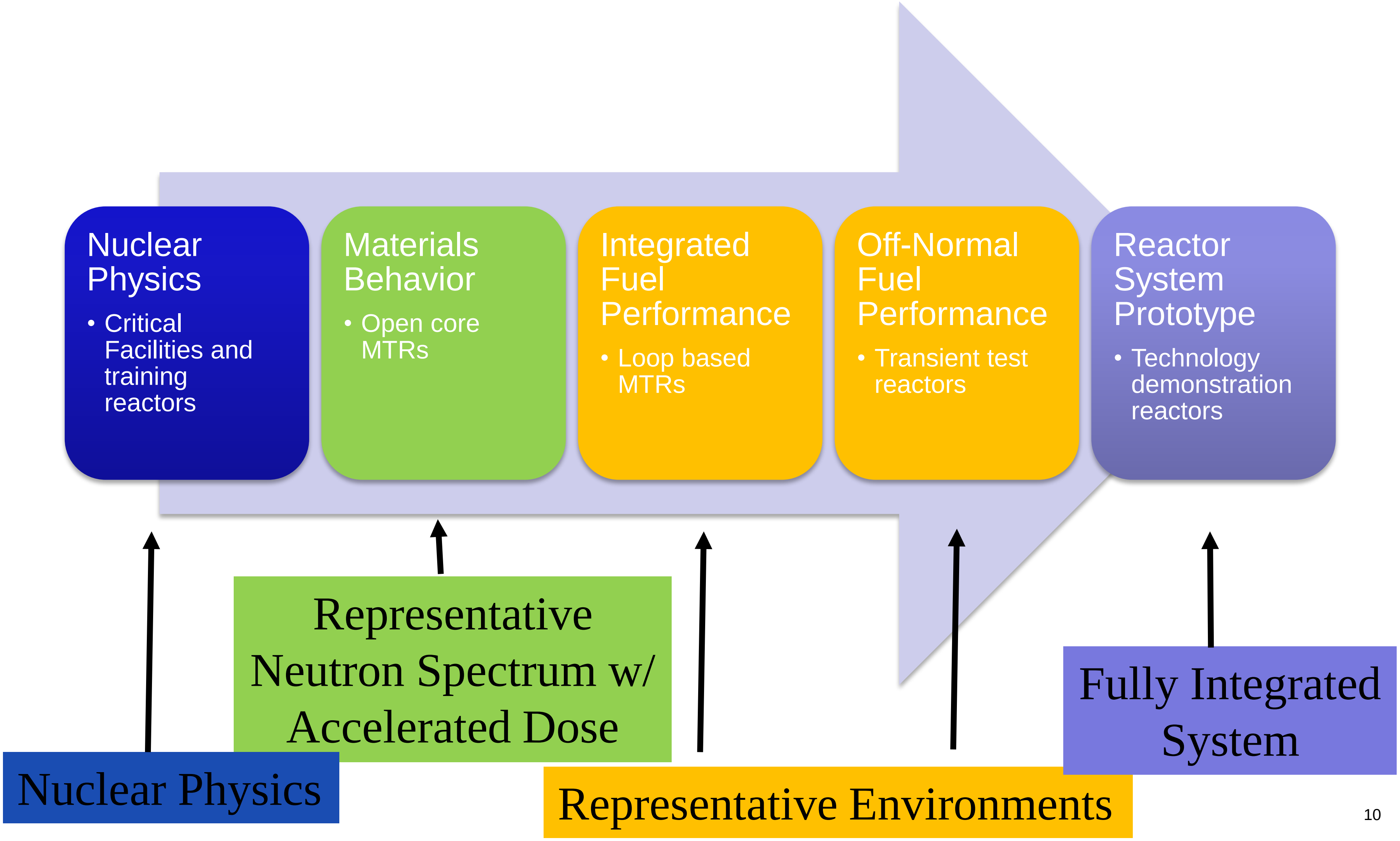
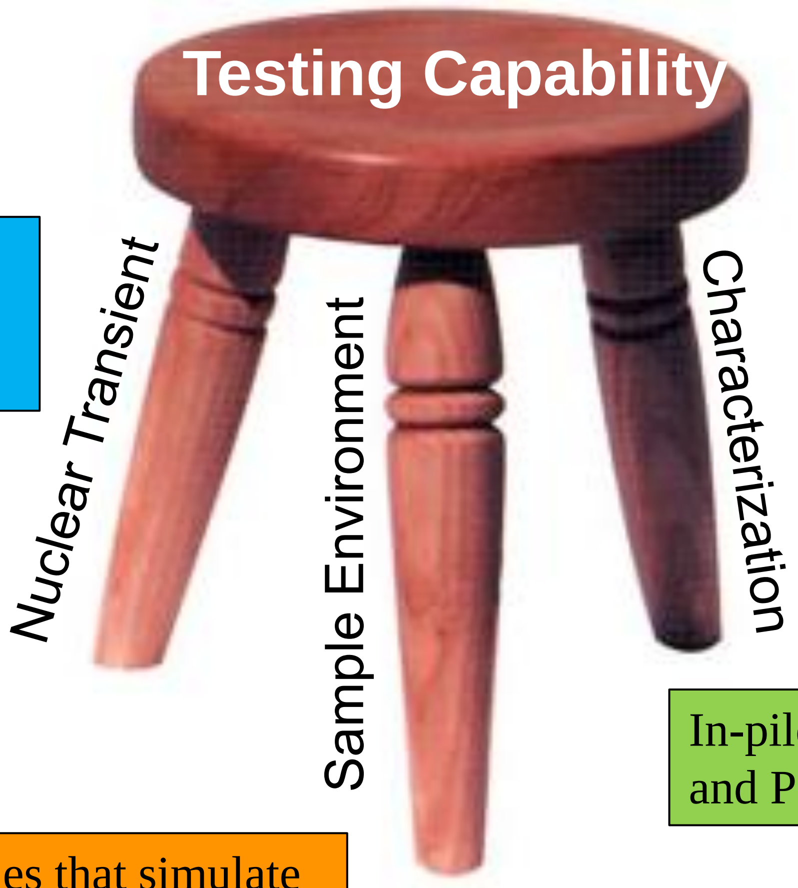
GEN-IV Research Reactor Need Spectrum



Irradiation Testing Capability for Integrated Fuel Testing



Neutron source defined by dose rate and energy spectrum

Experiment vehicles that simulate the desired environment

In-pile instrumentation and PIE capabilities

Traditional Nuclear Technology Development

Stage	$/test	*time*	# tests
Integral Irradiation Testing • Event simulations conducted in prototypic environments and configurations	$$$$	yrs	####
Semi-integral Testing • Partial event simulations in simplified environments that engage multiple relevant phenomena. • Tests can be used to validate integral M&S tools	$$$	~yr	###
Phenomenological Tests • Separate effects studies conducted to understand and describe individual physical phenomena • Analytical models developed for use in future integral testing	$$	mths	##
Material Properties • Definition of thermal physical and mechanical properties of materials and components used in fuel system.	$	wks	#

R&D is specific to a single fuel design.
Effort is expensive and takes a long time

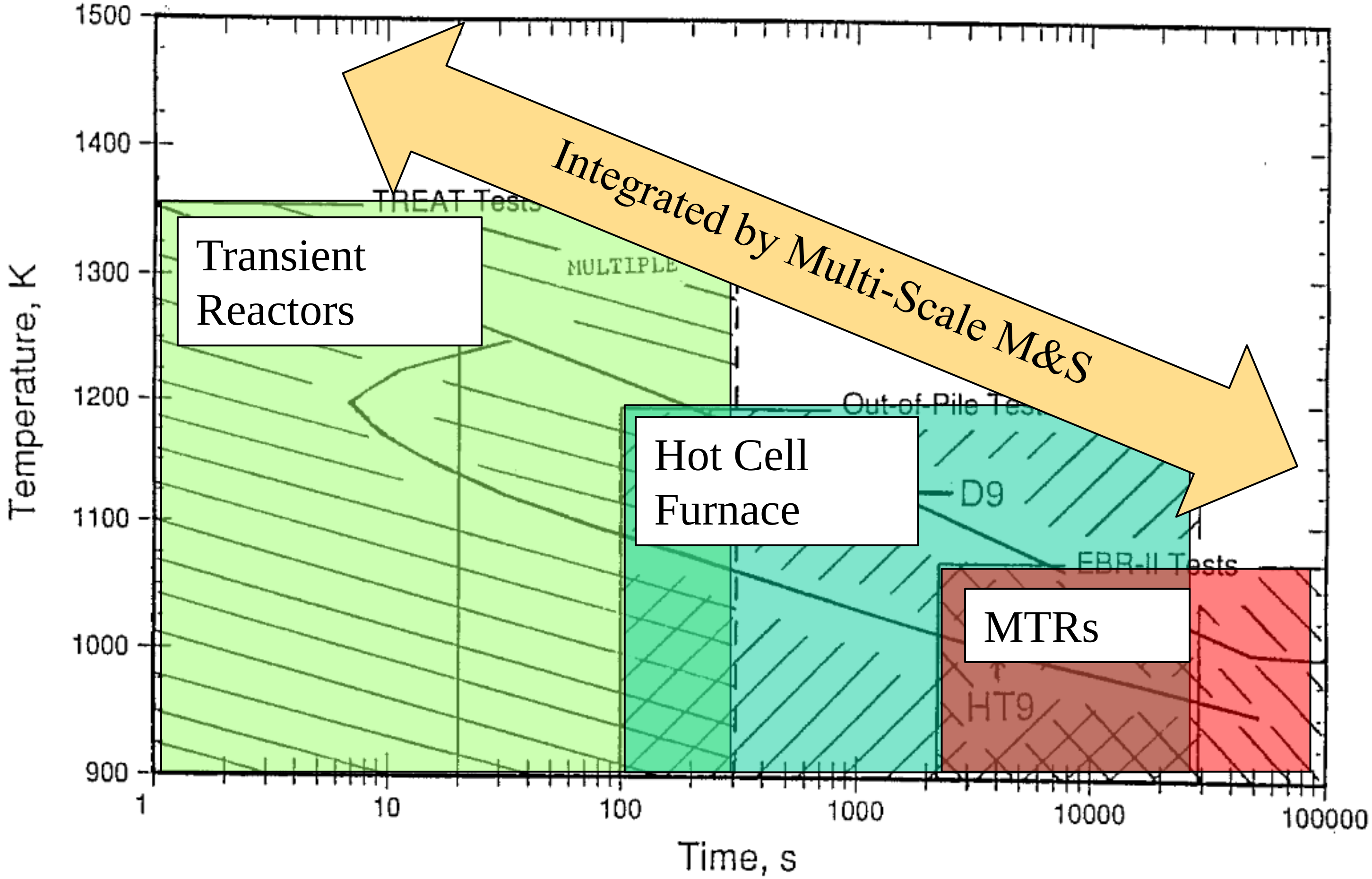
Modern Multi-Scale, Multi-Physics Development

R&D Integrated through M&S

	$/test	*time*	# tests
Integral Irradiation Testing • Event simulations conducted in prototypic environments and configurations	$$$$	yrs	#
Semi-integral Testing • Partial event simulations in simplified environments that engage multiple relevant phenomena. • Tests can be used to validate integral M&S tools	$$$	~yr	##
Phenomenological Tests • Separate effects studies conducted to understand and describe individual physical phenomena • Analytical models developed for use in future integral testing	$$	mths	###
Material Properties • Definition of thermal physical and mechanical properties of materials and components used in fuel system.	$	wks	####

R&D is relevant to many fuel designs.
Effort is still expensive and takes a long time

Integration of Fuel Research



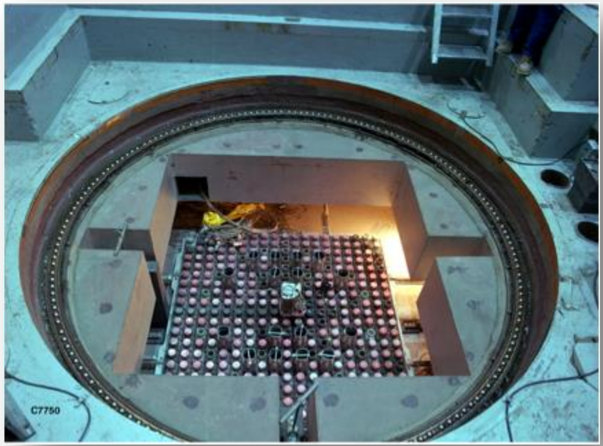
Summary

- Research reactors are flexible scientific tools used to support a wide variety of nuclear reactor applications
  - Current generation LWRs
  - Advanced reactor application
- R&D Infrastructure should support
  - Diverse modern technologies that are under development
  - Application of modern technology development methodologies
  - Structured technical collaboration to optimize utilization of specialized irradiation capabilities

Questions?

Post Irradiation Examination Facilities

November 9, 2017 (10:30-11:15)



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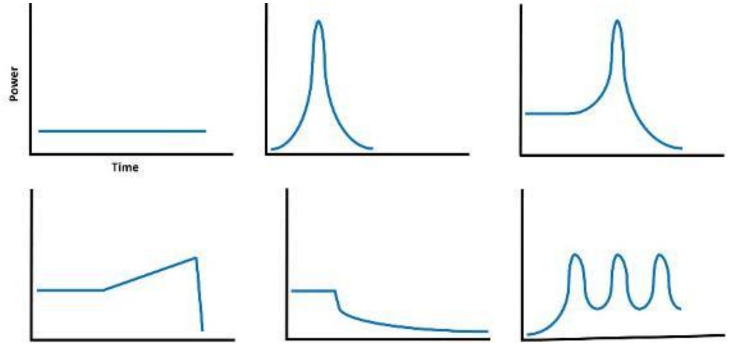
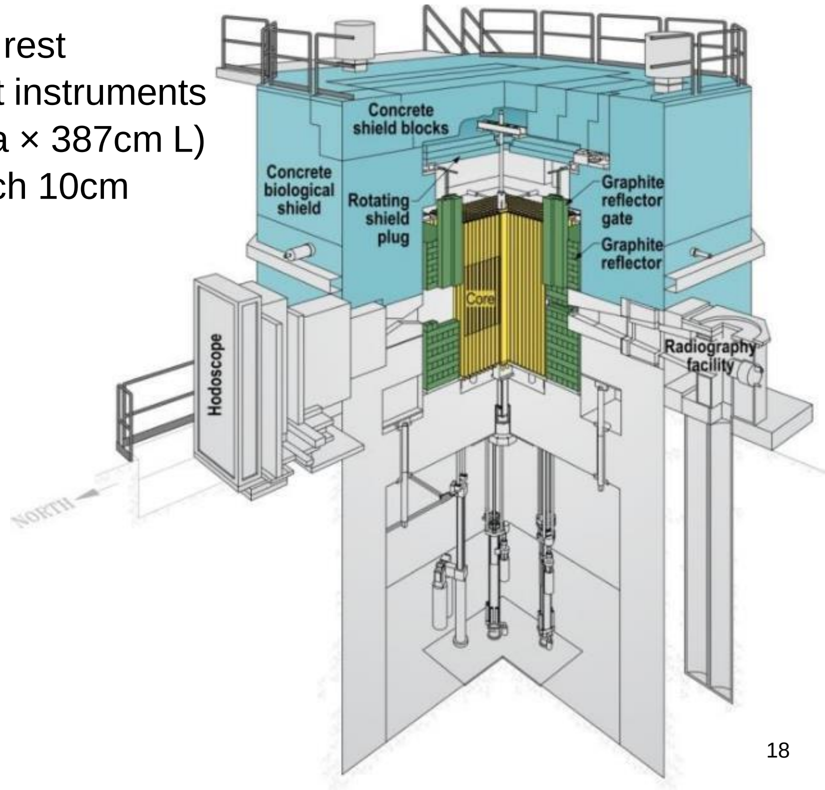
Introduction

- Transient Reactor Test (TREAT) resuming operations to support fuel safety testing
  - First tests to include baseline UO_2 in Zry fuels followed by fresh ATF specimens
- Graphite-based air-cooled reactor
  - 120 kW steady state, 19 GW peak in pulse mode
  - Virtually any power history possible within 2500 MJ max core transient energy
- Experiment design
  - Reactor provides neutrons, experiment vehicle does the rest
  - Safety containment, specimen environment, and support instruments
  - Handled outside concrete shield in cask (cavity 25cm dia × 387cm L)
  - Tests typically displace a few driver fuel assemblies (each 10cm square, 122cm L)
- 4 slots with view of core center, 2 in use
  - Fast neutron hodoscope, neutron radiography



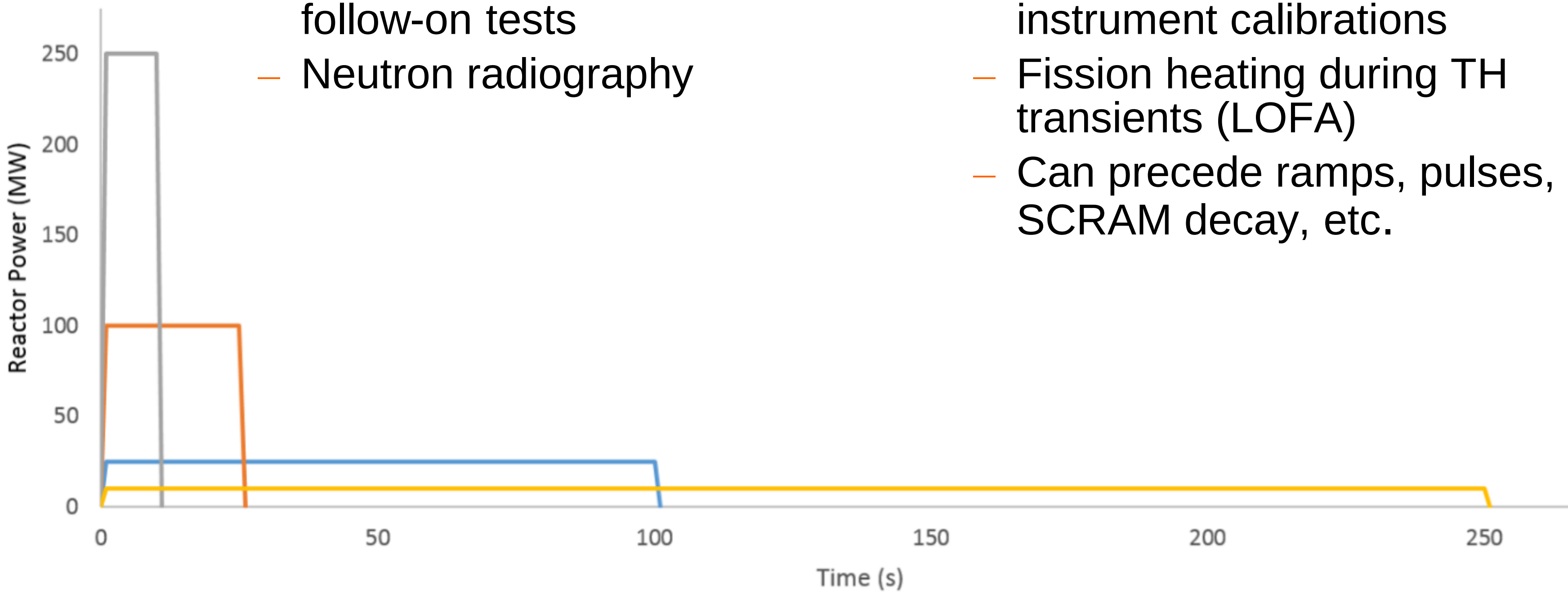
Example Transient Shapes



Transient Shaping

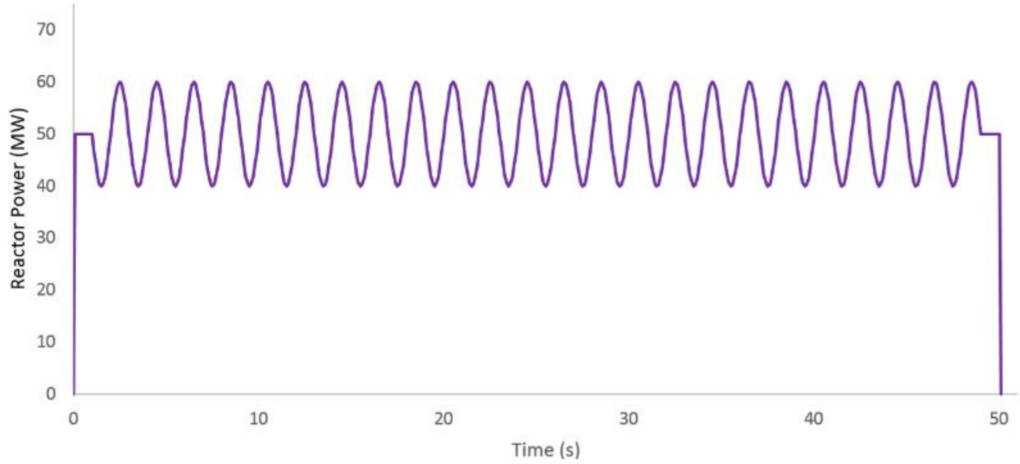
- TREAT is a transient reactor, not a pulse reactor
- Graphite heat sink, nimble control rod system → flexible power maneuvers

- Steady State
  - ≤120 kW steady state core power
  - Specimen power coupling measurements
  - Isotope build-in (e.g. ^{131}I) for follow-on tests
  - Neutron radiography
- Flattop Transients
  - “Flattops” >120 kW are considered transients
  - Virtually any power level, time limited by 2500 MJ
  - Heat balance and nuclear instrument calibrations
  - Fission heating during TH transients (LOFA)
  - Can precede ramps, pulses, SCRAM decay, etc.

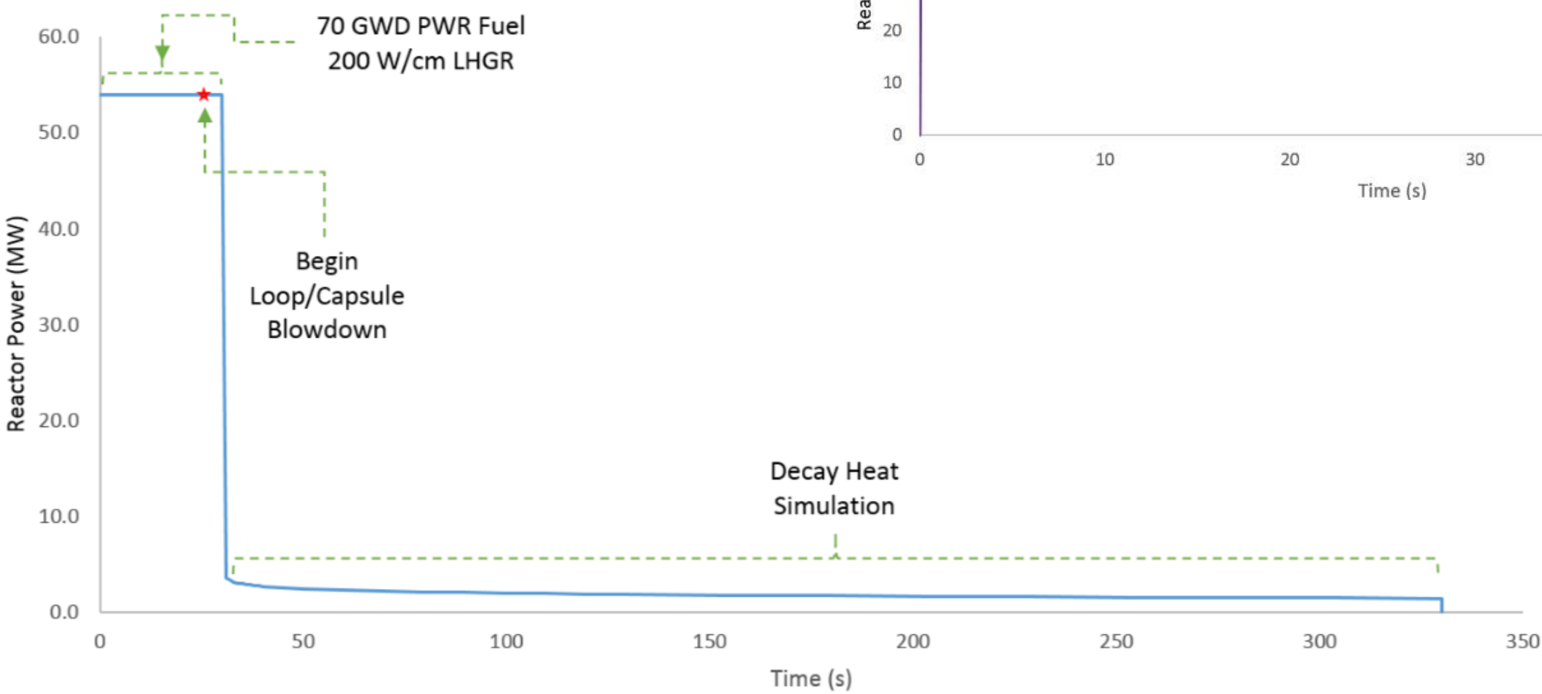


Transient Shaping

- Transient rod oscillations to simulate BWR void power instability

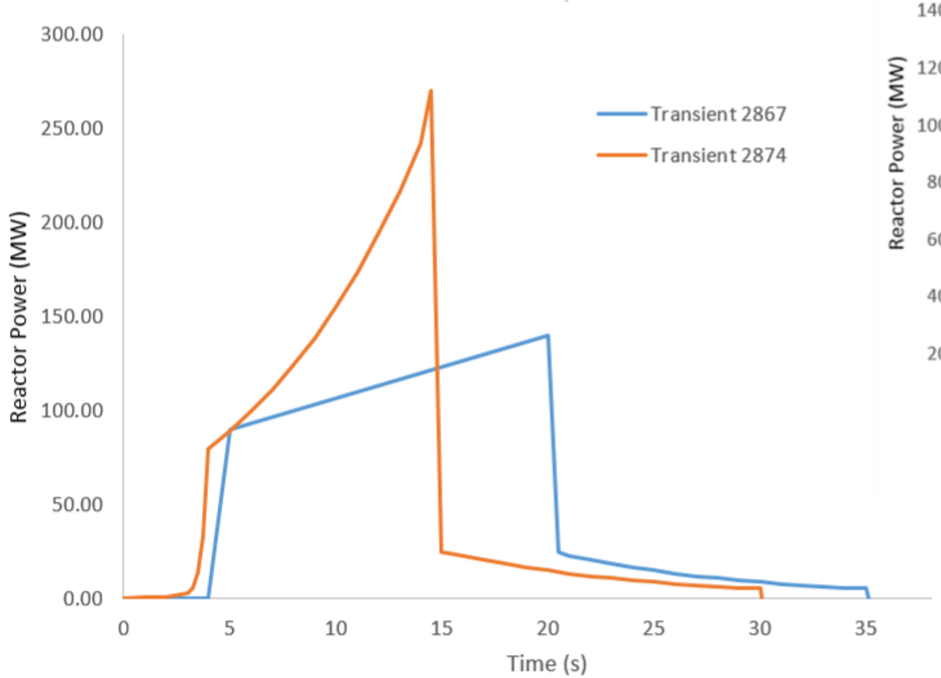


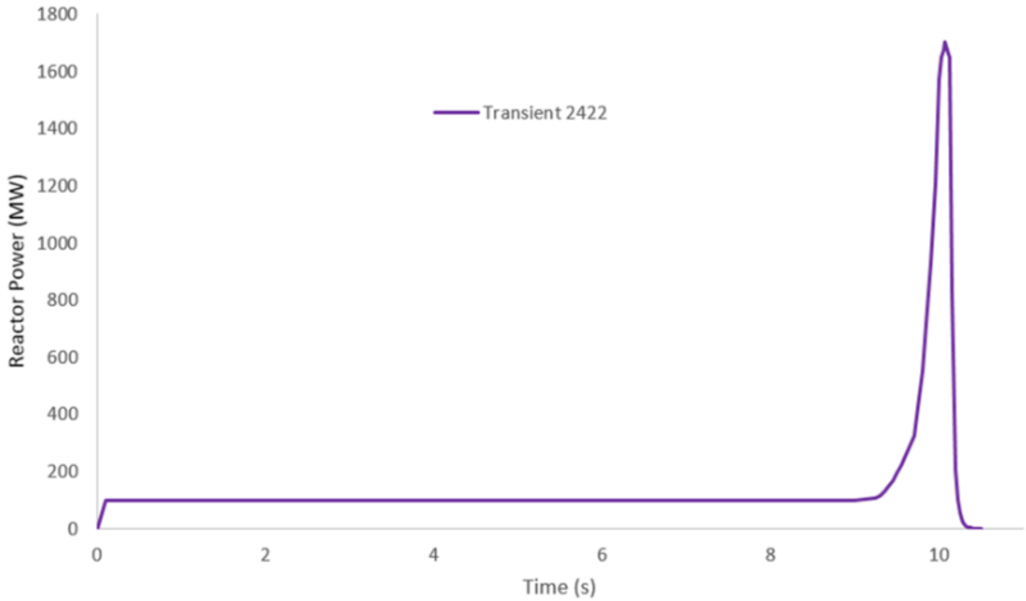
- Fission heat to provide internal heat generation (simulate LOCA decay)



Transient Shaping

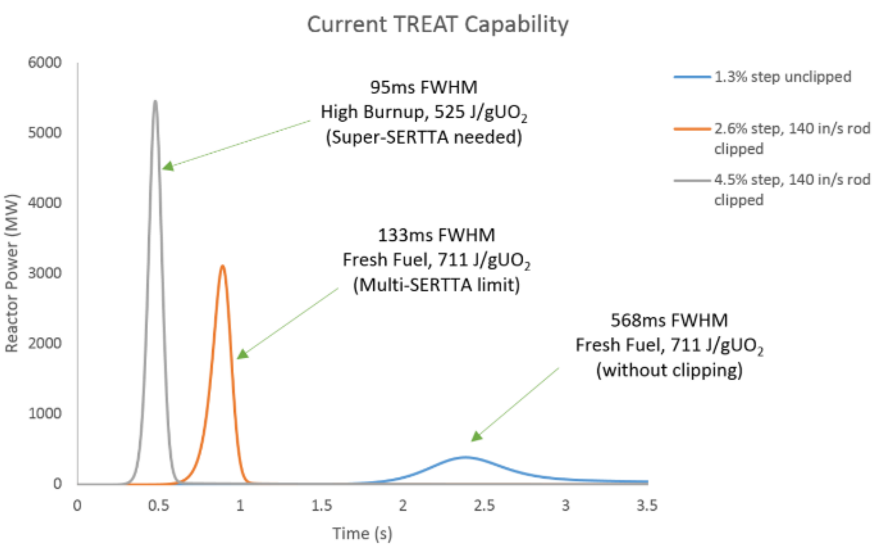
- TREAT has extensive historic with transient over power simulation
- Transient tuned to achieve desired fuel temperature and/or power history
- Ramp, pulse, shutdown, etc. can be triggered by experiment instruments





Transient Shaping

- Step insertion 4.5% Δk/k → 2500 MJ released in ~0.5 sec
  - Big dose for short-lived isotope studies
  - Facility's current energy limit
- Step insertion can follow a flattop Transient rod "clipping" → narrower pulses
  - Higher capacity vehicles needed for <100ms FWHM



- Enhanced clipping viable for narrower pulses
  - Better simulation of LWR HZP RIA
  - Drives high burnup LWR fuel to reg. limits in **46ms FWHM**
- Current LDRD project addressing enhanced clipping design